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LUNAR SURFACE ROVING VEHICLE. VOLUME 1:
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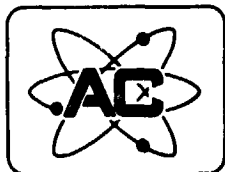
FINAL REPORT ON

DESIGN AND MANUFACTURE OF WHEELS FOR A DUAL-MODE (MANNED - AUTOMATIC) LUNAR SURFACE ROVING VEHICLE

VOLUME II PROPOSED TEST PLAN

Prepared for

GEORGE C. MARSHALL SPACEFLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Marshall Spaceflight Center, Alabama 35812
Under Contract NAS 8-25194



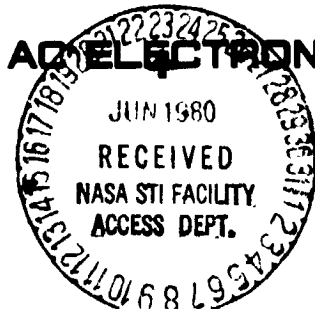
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LUNAR SYSTEMS

AD ELECTRONICS-DEFENSE RESEARCH LABORATORIES

SANTA BARBARA, CALIFORNIA



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MAY 1970

GENERAL MOTORS CORPORATION

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1.0 INTRODUCTION

Developmental testing is the initial testing required to meet the needs of the design engineer in his efforts to provide fully qualified flight hardware. Tests will cover performance, as well as critical environmental characteristics. The imposed tests are designed to provide confidence in the ability of the hardware to meet all design and mission requirements. Insofar as practical, the environmental conditions imposed will be in the sequence expected during the hardware's life from storage through the lunar mission. A principal outgrowth of the developmental test plan described herein will be test requirements, procedures and sequences for acceptance tests, and a qualification test program that provides maximum confidence in qualified hardware. It will further provide insight as to the needs for test equipment and facilities for qualification testing.

2.0 SCOPE

This developmental test plan has been prepared for the wheel and wheel drive assembly for the Dual-Mode (Manned/Automated) Lunar Surface Roving Vehicle (DLRV) to determine the degree of compliance with design and environmental conditions required for the successful completion of the vehicle mission prior to qualification testing. This allows the designer to make modifications as required to assure successful qualification testing.

The mission and environmental characteristics have been extracted from the Statement of Work (Exhibit A of NASA/MFSC RFQ DCN 1-9-21-00003) and "Natural Environment and Surface Design Criteria and Vehicle Minimum Mobility Requirements for Use in a Lunar Roving Vehicle Design Study" (Annex C of DCN 1-9-21-00003). The pertinent characteristics required of the wheel and traction drive assemblies have been incorporated in the specifications given below.

3.0 APPLICABLE DOCUMENTS

3.1 Specifications

DLRV Wheel Specification ES 10115 (Appendix C of this volume)

3.2 Drawings

RSK 20141, Wheel Assembly, Open, DLRV

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4.0 REQUIREMENTS

4.1 General

The environment and its effects on test hardware will be monitored by observing and recording the outputs of the following types of transducers:

- Temperature sensors
- Deflection indicators
- Voltage and current meters
- Strain gages
- Accelerometers
- Tachometers.

The above transducers are in addition to those associated with the environmental test facilities.

Functional parameters that will be measured by special instrumentation on the test hardware will include:

- Temperature of the wheel and wheel drive motor
- Wheel load
- Speed of the wheel and drive motor
- Voltage and current to the wheel drive motor
- Output torque to wheel
- Wheel vertical deflection
- Wheel and traction drive accelerations in three axes.

Wheel and wheel drive testing is planned at the assembly level only. Mechanical testing of the wheel and wheel drive assemblies is planned at ambient temperatures and will include load deflection and endurance tests. Mobility testing is also planned at ambient temperatures and will include drawbar pull and thrust at constant slip rates followed by motion resistance tests. Performance evaluation of the wheel and wheel drive assemblies is planned for both ambient and thermal-vacuum conditions.

4.2 Detail

4.2.1 Mechanical Testing, Ambient Conditions

4.2.1.1 Static Deflection

Static deflection tests on the complete wheel assembly are conducted on an apparatus similar to that shown in Figure 1. The apparatus consists of six load cells mounted between parallel plates which, in turn, are mounted to a standard milling machine table. Three cells are located at the corners of an isosceles triangle for measuring vertical loads. Two cells measure the lateral wheel loads, and a single cell is used to determine the tangential load. The upper plate is covered with a heavy material to provide a high friction surface.

The static deflection test facility uses a milling machine to provide the test loads and lateral, fore, and aft travel. The wheel is fastened rigidly to the locked milling machine arbor by a special adapter. The apparatus, in turn, is fastened to the machine feed table. This allows motion in any of the three principal axes.

A linear potentiometer provides an output signal proportional to table movement from a fixed reference point. A load is applied to the wheel and outputs from the load cells and the linear potentiometer are recorded directly on an X-Y plotter as wheel deflection vs load.

Static deflection tests are conducted at four locations spaced 90° apart. Two plots of deflection vs load are made at each position.

The footprint of the wheel is recorded under several wheel loading conditions and positions. Lateral and tangential wheel deflections are measured under several wheel loading conditions and positions.

4.2.1.2 Dynamic and Endurance

Dynamic tests of each wheel are conducted on a rolling road, with obstacles to simulate the moon's surface. Wheels are loaded vertically with design loads, and run for a distance 50% greater than the DLRV mission distance for each load.



Figure 1 Wheel Static-Load-Deflection Test Apparatus

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Figure 2 shows a rolling road facility used during breadboard wheel testing, with a breadboard wheel in place. An operator's control station is provided from which wheel speeds can be controlled and where parameters such as wheel speed, belt speed, wheel torque, and vertical acceleration are recorded. Accelerometers are located on the support structure and at the wheel. A wheel tachometer is located on the wheel drive, and the drive is strain-gaged to provide an output torque measurement.

Rough terrain conditions are simulated by obstacles attached to the surface of the rolling road. An obstacle size vs number-of-obstacles distribution has been developed from NASA Surveyor and Apollo particle size and distribution data (Figure 3). A modified distribution is also shown based on driver intelligence. This distribution eliminates obstacle sizes larger than 30 cm diam. A computer program computes the coordinates and obstacle size by using Monte Carlo methods on the modified distribution.

4.2.2 Mobility Performance Ambient Conditions

Soft soil tests are performed on a soil bin as described below to determine the soft soil mobility characteristics of the wheel. The tests determine drawbar-pull and thrust vs slip, as well as motion resistance for various wheel loads. Tests are conducted in air-dry, crushed silica sand for two conditions as specified in Table I. "Land Locomotion Soil Values" are determined by Bevameter Shear and Penetrometer devices. Soil angle of friction ϕ and cohesion c are determined from shear box tests.

The typical soil bin facility (Figure 4) is 40 ft long, with a soil section 60 in. wide and 30 in. deep. The rail-mounted test carriage provides mounting for wheels up to 48 in. diam. under loads of up to 2000 lb at speeds of 1 to 4 fps, and up to 1000 lb at 1 to 10 fps. A variable speed drive system is used to propel, brake, and control the carriage. The carriage, with its associated dynamometer and wheel drive, includes means for measuring drawbar-pull, wheel torque, sinkage, speed, and slip. The work car, mounted on the rail system, includes such soil equipment as a tiller, leveling blade, etc.

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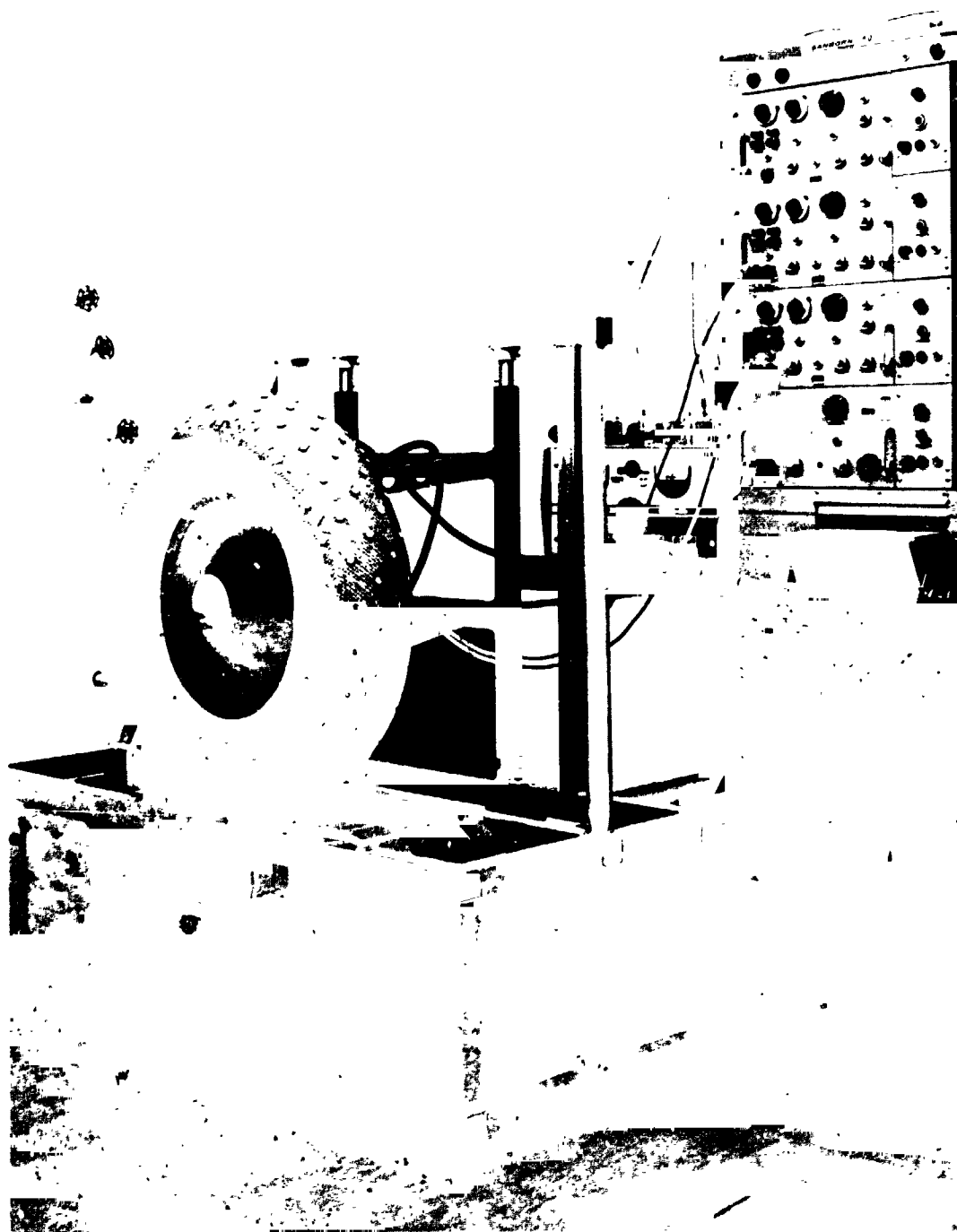


Figure 2 Roiling Road Facility

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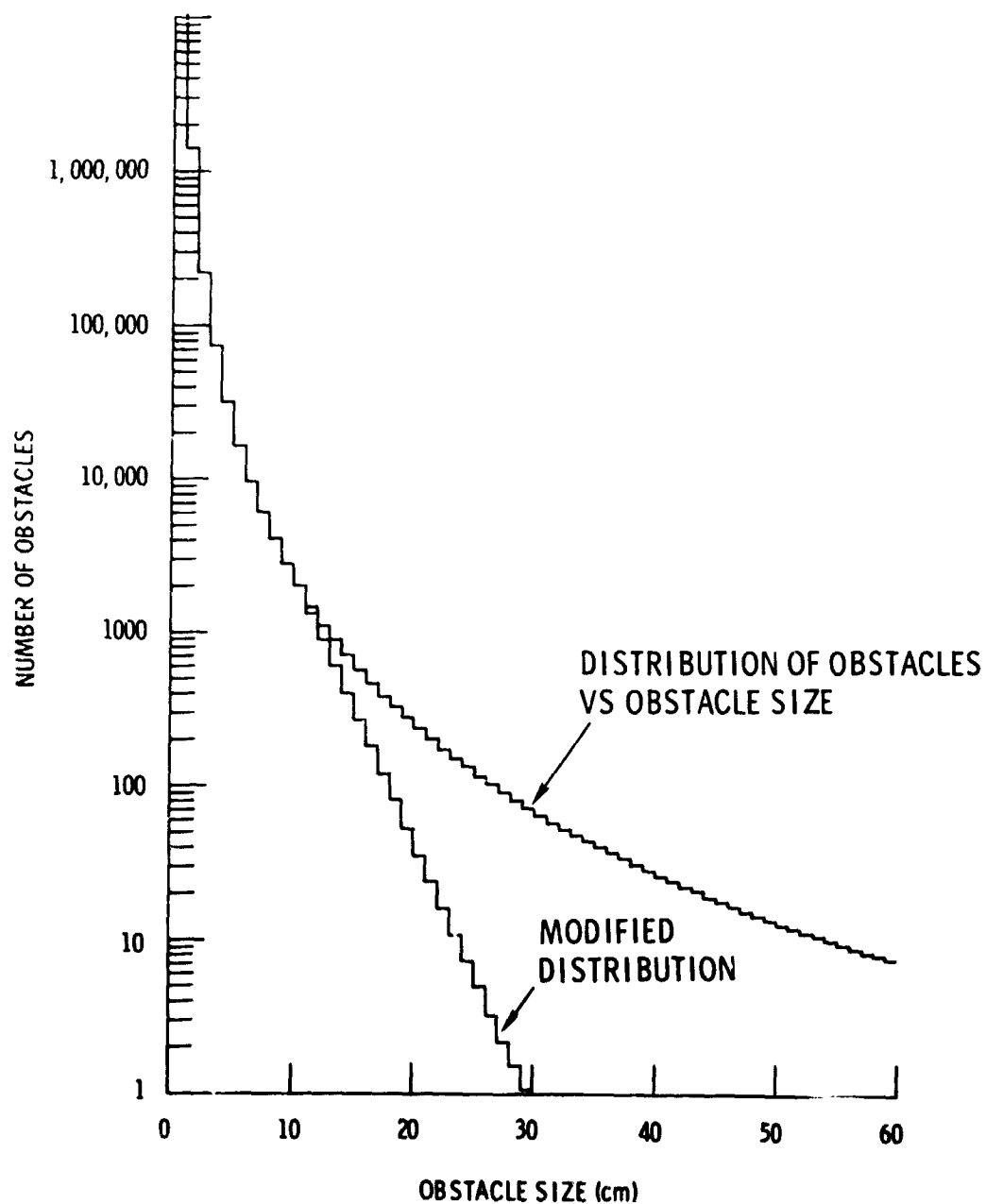


Figure 3 Distribution of Obstacles vs Obstacle Size
(For a 25 cm swath, 120 km long over
lunar surface)

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Figure 4 Soft Soil Test Setup

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SOIL DATA

Soil Factor	Crushed Silica Sand, Air Dry	
	Loose Condition	Compacted Condition
Bevimeter ϕ peak	$34^{\circ} \pm 3^{\circ}$	$40^{\circ} \pm 2^{\circ}$
Bevimeter ϕ ultimate	$34^{\circ} \pm 3^{\circ}$	$34^{\circ} \pm 3^{\circ}$
Bevimeter c		0 psi
k_{ϕ}	$4.0 \pm 0.6 \text{ lb/in.}^{n+2}$	$10 \pm 2 \text{ lb/in.}^{n+2}$
k_c	0 lb/in.^{n+1}	0 lb/in.^{n+1}
n	0.8	0.6
K	0.40 in.	0.35 in.
γ	$97 \pm 3 \text{ lb/ft}^3$	$107 \pm 2 \text{ lb/ft}^3$
Moisture Content	0.5%	0.5%
Shear Box ϕ peak	35.3°	40.0°
Shear Box ϕ ultimate	34.9°	33.8°
Shear Box c	0	0

4.2.2.1 Drawbar-Pull and Thrust vs Slip

Drawbar-pull and thrust versus slip tests are conducted on DLRV wheels. Prior to the start of each test, the soil will be tilled and leveled by using the soil bin work car.

Before, during, and at the completion of each day's testing, two penetration and one shear test will be conducted at three locations in the soil bin using the Bevameter soil test device mounted on the test carriage. Values of the pertinent soil parameters k_c/k_{ϕ} , n, c, and ϕ will be determined from the test data.

Drawbar-pull and thrust versus slip tests are conducted at three wheel loads, with each test repeated at least once, or as many times as required to obtain reasonable agreement between test data from consecutive test runs. The wheel and test carriage will be started at a predetermined synchronous speed (0 slip condition), and the speed of the test carriage decreased in a continuous manner to a zero speed, with the wheel speed held constant (100% slip condition). The rate of decrease in carriage speed will be adjusted so as to use the entire useable length of the bin in conducting the test, insofar as practical. Drawbar-pull, wheel torque (calibrated as thrust), wheel sinkage, wheel revolutions, and normal load will be recorded on a strip chart recorder.

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4.2.2.2 Motion Resistance

Motion resistance tests are conducted on DLRV wheels in the soil bin previously described. The soil will be tilled and leveled prior to each test with the soil work car as described above. At the start, during, and at the completion of each day's testing, two penetration tests and one shear test will be conducted at three locations in the soil bin using the Bevameter soil test device mounted on the carriage. Values of the pertinent soil parameters k_c , k_ϕ , n , c , and ϕ will be determined from the test data.

Motion resistance tests are conducted at three nominal wheel loads. Each test will be repeated at least once, or as many times as required to obtain reasonable agreement between test data from consecutive runs. To perform the motion resistance test, the carriage is run at a constant speed for the full length of the soil bin with the wheel in a free wheeling mode (drive chain detached). Motion resistance, wheel revolutions, carriage travel, normal load, and wheel sinkage will be recorded.

4.2.3 Evaluation of Complete Wheel and Wheel Drive Assemblies

4.2.3.1 Ambient Conditions

Evaluation of complete wheel and wheel drive assemblies at ambient temperatures is conducted on a test fixture similar to that shown in Figure 2. The test fixture is briefly described below.

Both steady-state and dynamic operation of the wheel and wheel drive assemblies are conducted. (Steady-state operation is defined as operation over a smooth surface; dynamic operation is defined as operation over obstacles that impose dynamic loads on the assemblies.) The test fixture provides a swinging arm to which the wheel drive motor of the wheel and drive assembly are mounted. The contact surface of this rolling road can be moved laterally to provide a variation in surface from smooth to one with obstacles. A remotely controlled brake is provided so that torques above those imposed by the free rolling road may be experienced by the system under test.

The wheel and wheel drive assembly are mounted in the test fixture. An initial "break-in" period is run with no vertical load on the assembly and on the smooth road surface prior to loading the assembly and before the dynamic testing. A calibration cycle is run before and after each test cycle. Test cycles will be repeated at least twice, or until consistent calibration results are obtained.

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4.2.3.2 Thermal Vacuum Conditions

A photograph of a test fixture to be used for thermal vacuum testing is shown in Figure 5, and described briefly below.

The drive motor is mounted to a bearing-supported weighted frame that permits the wheel/drive assembly vertical freedom of motion when driving the rolling road. The road is inclined at 82° to the horizontal to simulate lunar gravity.

When the drive assembly is attached to the motor, the high-speed parts of the drive and the motor are sealed from the vacuum. The internal volume is open to a port used for charging and monitoring pressure. To facilitate temperature control, the motor and associated temperature control lines are insulated with multiple layers of aluminum foil.

The rolling road provides a simulated road bed for the test. It is approximately 120 in. in length. The running surface is a series of aluminum plates covered with a suitable surface for traction. Water is circulated through the bearing housing to maintain nominal working temperatures for the brake assembly and transducer.

A typical space simulator system used for the thermal vacuum tests is shown in Figure 6.

The chamber is a horizontal end-loaded system 10 ft in diameter and 10 ft long. The working space inside the thermal shroud is 7-1/2 ft diam. and 9 ft long. A dolly door at one end of the chamber is supported on casters to expedite installation of test assemblies. A cantilevered double boom extending from the dolly door supports the test fixture. There is ample test space within the chamber for the fixture, as well as a large number of feedthroughs for instrumentation and fluid lines. Ports at the opposite end of the chamber provide a complete field of view of the fixture for visual and photographic observations of the tests.

The LN_2 shroud has a 4-zone control over a temperature range of -320° to $+200^{\circ}\text{F}$. The chamber has an ultimate performance of 2×10^{-10} torr. It is equipped with four pumping systems: a 10,000 liters/sec ion pump, a 100,000 liters/sec titanium sublimation pump, two Roots blowers, and four mechanical pumps. It has a pumping rate of 300 torr to 5 torr in 85 sec, and 760 torr to 1×10^{-9} torr in 24 hours, with a 5×10^{-5} torr liter sec dry nitrogen in-leak.

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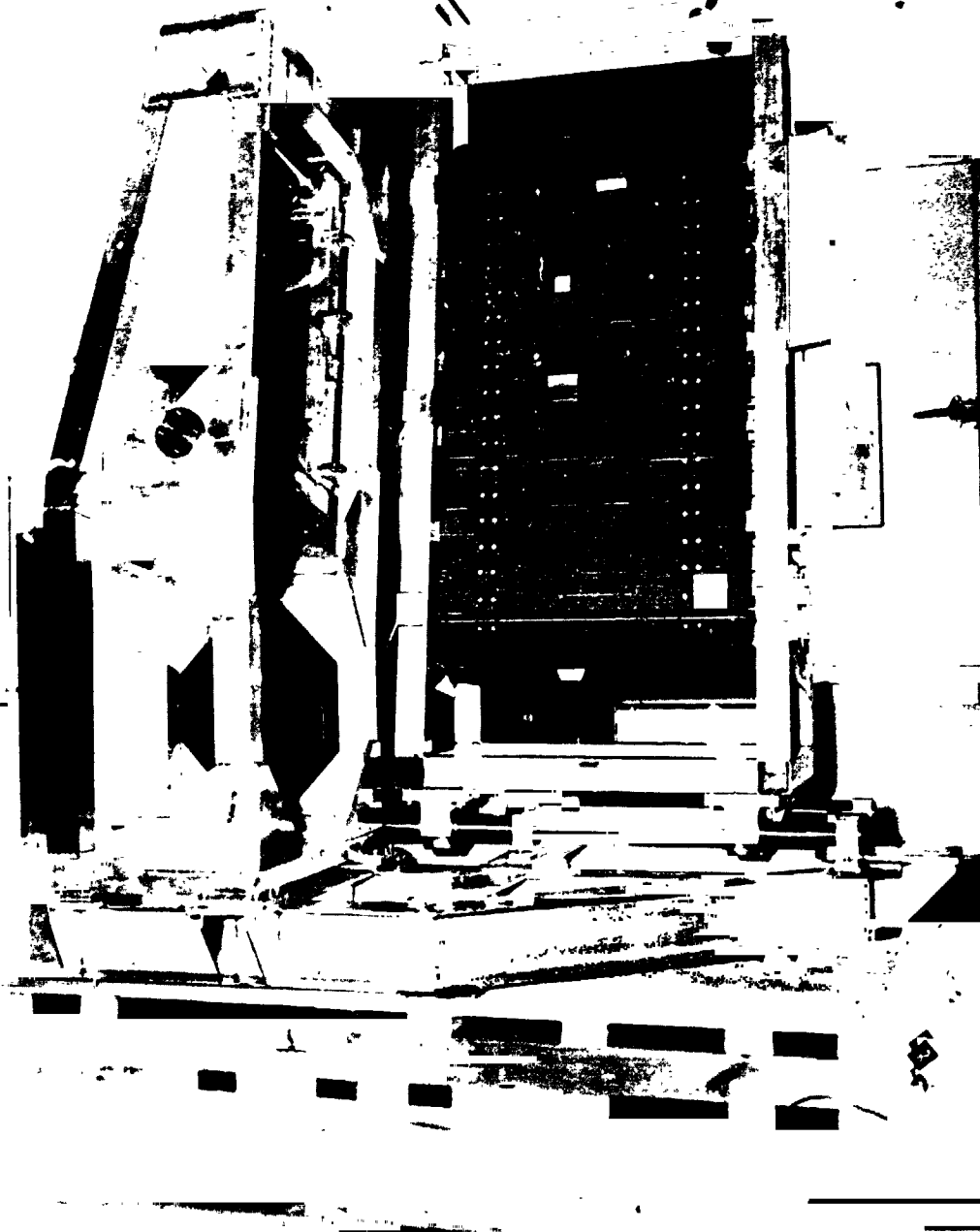


Figure 5 Test Fixture Used in Thermal Vacuum Chamber

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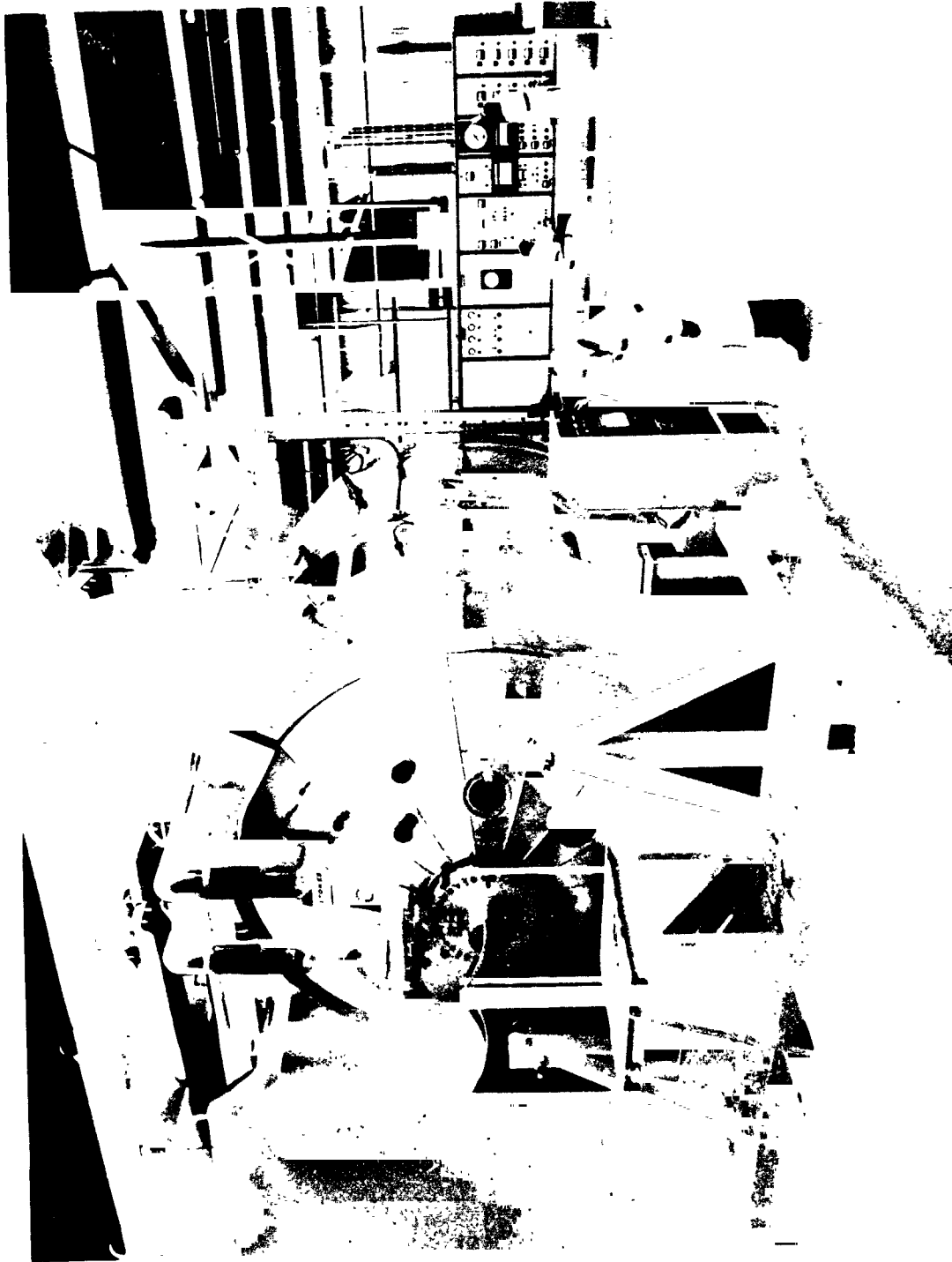


Figure 6 Typical Space Simulator Chamber

Testing is accomplished by using the test fixture of Figure 5 installed in a thermal vacuum test chamber to permit both steady-state and dynamic operation of the test assemblies. To the extent practical, instrumentation and fixture mechanisms shall be protected from the full thermal vacuum. Road, chamber wall, and drive motor temperatures, each independently controlled, shall be used to establish temperature environments for the test assemblies. A vacuum environment of better than 10^{-7} torr pressure is desired for the test.

The wheel and wheel drive assembly are assembled in the test fixture with a nominal vertical load applied. The assembly will be run through a calibration cycle before and after thermal vacuum tests. During thermal vacuum testing, temperatures, torques, pressures, speed, and cycles are recorded.

5.0 FACILITIES, TRANSDUCERS AND INSTRUMENTATION REQUIREMENTS

5.1 Facilities

The following is a summary list of facilities which are required to perform the developmental tests described above.

5.1.1 Mechanical Testing

5.1.1.1 Static Deflection Tests

- Three-axis table (milling machine)
- Special 3-axis platform with high friction surface
- Wheel support fixture.

5.1.1.2 Dynamic and Endurance Tests

- Rolling road facility with wheel and wheel drive special support structure
- Wheel load weights
- Road obstacles.

5.1.2 Mobility Performance, Ambient Conditions

5.1.2.1 Drawbar-Pull and Thrust versus Slip

- Large Soil Bin
- Soil Bin Test Carriage

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- Weights
- Work Car including tiller, leveling blade and compactor.

5.1.2.2 Motion Resistance

- Same as 5.1.2.1 above.

5.1.3 Evaluation of Complete Wheel and Wheel Drive Assemblies

5.1.3.1 Ambient Conditions

- Rolling Road facility with wheel and wheel drive special supporting structure
- Wheel Load Weights
- Road Obstacles.

5.1.3.2 Thermal Vacuum Conditions

- Rolling Road facility with wheel and wheel drive special supporting structure
- Space Simulator Thermal-Vacuum Chamber
- Wheel Load Weights
- Road Obstacles.

5.2 Transducers

The following is a summary list of transducers required to perform the developmental tests described above.

5.2.1 Mechanical Tests

5.2.1.1 Static Deflection Tests

- (See 5.1.1.1 above — Load cells (6) and linear potentiometers (3) built into special 3-axis test apparatus.)

5.2.1.2 Dynamic and Endurance

- Wheel tachometer
- Wheel odometer
- Accelerometers, 3-axis

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- Road tachometer
- Wheel torque strain gages.

5.2.2 Mobility Performance Evaluation, Ambient Conditions

5.2.2.1 Drawbar-Pull and Thrust versus Slip

- (See 5.1.2.1 above — two-axis load cell dynamometer wheel torque cells, linear potentiometers, odometer and Bevameter soil test device built into test carriage.)

5.2.2.2 Motion Resistance

- Same as 5.2.2.1 above.

5.2.3 Evaluation of Complete Wheel and Wheel Drive Assemblies

5.2.3.1 Ambient Conditions

- Wheel tachometer
- Wheel odometer
- Accelerometers, 3-axis
- Road tachometer
- Wheel torque strain gages.

5.2.3.1 Thermal-Vacuum Conditions

- Wheel tachometer
- Wheel odometer
- Accelerometers, 3-axis
- Road tachometer
- Wheel torque strain gages
- Thermocouples.

5.3 Instrumentation

The following is a summary list of instrumentation required to perform to developmental tests described above.

5.3.1 Mechanical Tests

5.3.1.1 Static Deflection Tests

- X-Y plotter
- Bridge balance box.

5.3.1.2 Dynamic and Endurance Tests

- Strip recorder and amplifiers
- Power supply (wheel drive motor).

5.3.2 Mobility Performance Evaluation, Ambient Conditions

5.3.2.1 Drawbar-Pull and Thrust versus Slip

- Strip recorder and amplifiers
- Power supply (wheel drive motor).

5.3.2.2 Motion Resistance

- Same as 5.3.2.1 above.

5.3.3 Evaluation of Complete Wheel and Wheel Drive Assembly

5.3.3.1 Ambient Conditions

- Strip recorder and amplifiers
- Power supply (wheel drive motor)
- Rolling road remote controls.

5.3.3.2 Thermal-Vacuum Conditions

- Strip recorder
- Power supply (wheel drive motor)
- Rolling road remote controls.
- Chamber monitoring instruments

APPENDIX A
PRELIMINARY MECHANICAL
TEST SPECIFICATION
FOR THE
DUAL-MODE LUNAR ROVING VEHICLE (DLRV) WHEEL

1. SCOPE

1.1 This specification covers the tests to be performed on DLRV wheels to determine mechanical and rough surface mobility characteristics. These tests shall consist of load-deflection, dynamic checkout, cornering, and single obstacle, smooth surface, and random obstacle endurance tests.

2. APPLICABLE DOCUMENTS

2.1 Drawings

AC-DRL

RSK 20111 Wheel assembly

3. GENERAL

3.1 Test Article

The test article is shown in RSK 20111 and described briefly below.

The wheel concept is a single-mesh, open-wire frame design with a chevron tread. The wheel consists of a rim, disc, flexible woven wire outer frame, stiff inner frame, tread, and necessary fasteners. The rim and disc are spun from 2024 aluminum alloy sheet. The disc and rim are then trimmed and heat-treated.

The inner frame is essentially a stiff spring which limits the vertical and lateral deflection of the outer frame and absorbs impact loads. It consists of formed loops interconnected by a hat-section circumferential ring and riveting the conical rings to the loop ends.

The flexible wire frame is woven from music spring wire consisting of 800 interwoven wires in a 0.187 in. mesh. Each wire is crimped at fixed intervals using a crimping machine. The crimped wires are then woven into a flat mesh and the ends of the mesh are interwoven to form a cylinder. The cylinder ends are clamped in a stress-relief fixture to form a torus which is then stress-relieved and removed from the fixture.

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The tread strips are applied to the wire frame in a chevron pattern. Each strip is secured to the woven wire by a rivet which passes through the tread strip and the wire mesh and is headed over a washer on the back side of the mesh. A tubular spacer between the tread strip and the securing washer prevents clamping of the wire mesh.

3.2 Single Obstacle

A 4 in. x 4 in. x 12 in. wide square profile bump, fabricated from aluminum, shall be used in the single obstacle tests specified in paragraph 5.4.

3.3 Random Obstacle Course

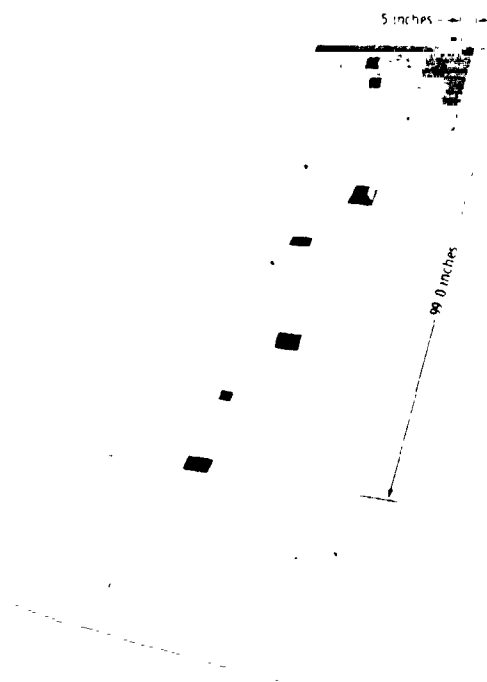
The random obstacle course to be used in the endurance tests specified in paragraph 5.5.2 shall consist of a number of geometric shapes fabricated from aluminum. The shapes shall be fabricated and positioned in accordance with Figure A-1.

4. TEST EQUIPMENT

4.1 The equipment required to perform the tests specified herein is listed in Table A-I and described below.

Table A-I

<u>Test</u>	<u>Paragraph</u>	<u>Test Equipment</u>
Load-Deflection	5.1	(1) 3-Axis Static-Load-Deflection Apparatus (2) Linear Potentiometer (3) Bridge Balance Box (4) 3-Axis Table (5) Wheel Support Fixture
Dynamic Checkout	5.2	(1) Rolling Road Facility (2) Parallel Arm Support Structure including (a) Suspension System (b) Wheel Drive and Control (3) Instrumentation (a) Accelerometers (b) Wheel Revolution Counter (c) Wheel Tachometer (d) Belt Tachometer (e) Wheel Torque Gages (4) Weights (5) Recorders

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	OBSTACLE x (INCH) (along road)	POSITION y (INCH) (across road)	OBSTACLE TYPE	OBSTACLE DIMENSIONS (INCHES)
1.	0.0	5	Rectangle	Length =3, Width =3, Height =3.15
2.	7.5	16.1	Trapezoid	Bot.side = 3, Top side =2, Height =1.18
3.	15.0	14.4	1/2 Cylinder	Length = 2, Radius = 1.57
4.	46.5	10.5	Trapezoid	Bot.side =4, Top =2, Height = 1.18
5.	61.5	14.8	Rectangle	Length =3, Width =2, Height =2.76
6.	79.0	11.6	1/2 Cylinder	Length =3, Radius = 1.97
7.	89.0	16.8	Trapezoid	Bot.side =2.5, Top side =1.5, Height=1.18
8.	99.0	16.4	Rectangle	Length =3, Width =2, Height = 1.18

Coordinates are center of obstacle

Figure A-1 Obstacle Configurations and Arrangement

Table A-I (Cont.)

<u>Test</u>	<u>Paragraph</u>	<u>Test Equipment</u>
Cornering	5.3	Same as 5.2
Single Obstacle	5.4	(1) Same as 5.2 (2) 4-inch Square Bump
Endurance	5.5	(1) Same as 5.2 (2) Obstacle Course

4.1.1 3-Axis Test Apparatus and Associated Equipment

The test apparatus consists of six load cells mounted between two parallel plates. Three load cells are located at the corners of an isosceles triangle for measuring vertical load. Two load cells measure the lateral wheel loads. A single load cell is used to determine the tangential load. The upper plate is covered with heavy emery cloth to provide a high friction surface.

The wheel spring rate test setup uses a milling machine to provide the test loads and travel. The wheel is fastened rigidly to the locked arbor by means of a special adapter. The test apparatus, in turn, is fastened to the machine feed table which allows motion in any of the three principal axes. The milling machine applies a load to the wheel and, in conjunction with a linear deflection potentiometer, provides a readout to an X-Y plotter which gives the plot directly.

The linear potentiometer provides a readout of the table movement from a fixed reference point.

4.1.2 Rolling Road Facility and Associated Equipment

The rolling road is a variable-speed (0 to 18 fps) moving belt facility used for the investigation of wheel dynamics and stability evaluation.

Rough terrain conditions are simulated by mounting obstacles of various shapes, sizes and distribution on the normally smooth surface.

An operator's control station is provided from which the belt and wheel speeds may be controlled, and where parameters such as wheel speed, belt speed, wheel torque, and

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vertical acceleration may be recorded. Accelerometers are located on the support structure and at the wheel. A wheel tachometer is located on the wheel drive and the drive is strain-gaged to provide an output torque measurement.

5. TEST PROCEDURES

Mechanical mobility tests shall be conducted in accordance with the procedures described in this paragraph.

5.1 Load-Deflection Tests

Load-deflection tests shall be conducted on the test article described in para. 3.1. Load-deflection tests shall be conducted at four locations (spaced 90 deg. apart) on each wheel. Two tests shall be run at each location. The test sequence shall be as described below.

5.1.1 Set-Up

The 3-axis test apparatus shall be placed on the table of the milling machine and appropriate connections shall be made to the bridge balance box and the X-Y plotter. The linear potentiometer shall be located to record the wheel deflection in either the vertical, lateral, or longitudinal direction. The wheel shall be mounted rigidly to the wheel support structure which in turn shall be attached to the overarm supports of a horizontal milling machine.

5.1.2 Vertical Load - Deflection

The wheel shall be deflected from 0 to 4 inches and the load-deflection curve shall be recorded.

The wheel footprint shall be recorded at 30, 45, 60 lb and at a maximum deflection.

5.1.3 Lateral Load-Deflection

A vertical load of 60 lb shall be applied to the wheel. The wheel shall then be deflected laterally until the wheel slippage occurs at the high friction surface. The lateral load-deflection curve shall be recorded.

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5.1.4 Tangential Load-Deflection

A vertical load of 60 lb shall be applied to the wheel. The wheel shall then be deflected tangentially until slippage occurs at the high friction surface. The longitudinal load-deflection curve shall be recorded.

5.2 Dynamic Checkout Tests

The wheel shall be mounted on the rolling road wheel support structure. Each test article wheel shall be subjected to one hour of continuous running at 60 lb wheel load. The wheel speed and torque shall be in accordance with the mission profile.

Wheel speed, torque and number of wheel revolutions shall be recorded. The wheels shall be observed and its performance characteristics shall be noted. Photographs and motion pictures shall be taken whenever necessary.

5.3 Cornering Test

The wheel shall be mounted on the rolling road support structure and a wheel load of 60 lb shall be applied. The wheel shall be yawed at angles of 5, 10, and 15 deg. with respect to the rolling road belt and shall be run at 4, 8, 12 and 16 km/hr speed. The behavior of the wheel shall be observed and noted.

5.4 Single Obstacle Test

A single 4 in. x 4 in. x 12 in. wide obstacle shall be mounted on the rolling road. Each test article wheel shall be mounted on the rolling road support structure and a wheel load of 60 lb shall be applied. The wheel shall be run at least 20 times over the obstacle at speeds of 4, 8 and 12 km/hr. Wheel speed and torque, and wheel and chassis (support structure) acceleration shall be recorded.

5.5 Endurance Tests

Endurance tests shall be conducted on the wheel with wheel loads in accordance with the mission profile. The endurance tests shall consist of smooth surface tests and obstacle course tests for a total of 625,000 cycles or until significant structure degradation of the wheel occurs.

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5.5.1 Smooth Surface Tests

Smooth surface endurance tests shall be conducted in accordance with the mission profile for a total of 425,000 cycles.

Wheel speed and torque, and wheel and chassis accelerations as well as wheel revolutions shall be recorded.

5.5.2 Obstacle Course Tests

Both test article wheels shall be run over the obstacle course described in para. 3.3. The cover shall be mounted on the rolling road belt. The wheel drive shall be set at a constant voltage and the wheel speed and torque will be allowed to vary in accordance with the speed-torque characteristics of the wheel drive system. The test sequence shall be as follows:

1. 80,000 cycles at a nominal wheel speed of 4 km/hr
2. 80,000 cycles at a nominal wheel speed of 8 km/hr
3. 40,000 cycles at a nominal speed of 12 km/hr.

The wheel load shall be a nominal 60 lb. Wheel speed and torque, wheel and chassis accelerations, and wheel revolutions shall be recorded. Motion pictures shall be utilized to record wheel deflections.

6. TEST CONDITIONS

6.1 All tests shall be conducted under room ambient conditions.

7. REQUIREMENTS

7.1 General

Since the purpose of these tests is the evaluation of the relative mechanical and dynamic performance of the wheel, there are no specific performance requirements to be met.

7.2 Documentation

All data should be recorded on approved log sheets or collected on instrumentation readout charts. Each sheet of data shall be signed and dated by the person responsible for taking the data and the responsible engineer supervising the test. In addition, a log

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book with approved log sheets shall be maintained daily, noting the test activity for the day, problems, test conditions, and other pertinent data that might not otherwise be recorded.

In addition, unique test conditions noted during actual testing shall be recorded photographically.

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APPENDIX B
PRELIMINARY SOFT SOIL
TEST SPECIFICATION
FOR THE
DUAL-MODE LUNAR ROVING VEHICLE (DLRV) WHEEL

1. SCOPE

1.1 This test specification covers the tests to be performed on the DLRV wheel to verify the soft soil mobility characteristics. The tests shall consist of drawbar-pull versus slip, motion resistance, and effective radius tests.

2. APPLICABLE DOCUMENTS

2.1 Drawings

AC-DRL RSK 20111 Wheel Assembly

3. GENERAL

3.1 Test Articles

The test article is shown in RSK 20111 and is described briefly below.

The DLRV wheel concept is a single-mesh, open-wire frame design with a chevron tread design. The wheel consists of a rim, disc, stiff inner frame, flexible woven outer frame, tread, and necessary fasteners. The rim and disc are spun from 2024 aluminum alloy sheet. The disc and rim are then trimmed and heat-treated.

The inner frame is essentially a stiff spring which limits the vertical and lateral deflection of the outer frame and absorbs impact loads. It consists of formed loops interconnected by a hat-section circumferential ring. The inner frame is assembled by riveting the loops to the circumferential ring and riveting the conical rings to the loop ends.

The flexible wire frame is woven from music spring wire. It consists of 800 interwoven 0.032 in. diam. wires in a 0.187 in. mesh. Each wire is crimped at fixed intervals using a crimping machine. The crimped wires are then woven into a flat mesh and the ends of the mesh are interwoven to form a cylinder. The cylinder ends are clamped in a stress-relief fixture to form a torus which is then stress-relieved and removed from the fixture.

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The tread strips are applied to the wire frame in a chevron pattern. Each strip is secured to the woven wire by a rivet which passes through the tread strip and the wire mesh and is headed over a washer on the back side of the mesh. A tubular spacer between the tread strip and the securing washer prevents clamping of the wire mesh.

3.2 Soils

All soft soil tests specified herein shall be conducted in crushed Basalt sand having the following mechanical soil properties (Land Locomotion Soil Values):

$$\phi = 35^{\circ} \pm 4^{\circ}$$

$$c = 0 \text{ to } 0.05 \text{ lb/in.}^2$$

$$k_{\phi} = 3 \text{ lb/in.}^2/\text{in.}$$

$$k_c = 0. \text{ to } 0.4 \text{ lb/in. /in.}$$

$$n = 1$$

$$K = 0.7 \pm 0.3 \text{ in.}$$

$$\gamma = 90 \pm 5 \text{ lb/ft}^3$$

Tests shall be conducted at soil conditions with properties within the range specified above.

4. TEST EQUIPMENT AND PROCEDURES

4.1 Test Equipment

The test equipment required to perform the test specified herein is listed in Table B-I, followed by a brief description.

Table B-I
TEST EQUIPMENT

- 1) Large Soil Bin
- 2) Soil Bin Test Carriage including:
 - a) Two-axis load cell dynamometer
 - b) Wheel Torque Cell
 - c) Sinkage Potentiometer
 - d) Carriage Travel Potentiometer
 - e) Wheel Revolution Counter
 - f) Bevameter Soil Test Device

Table B-1 (Cont.)

- 3) Recording Equipment
- 4) Weights
- 5) Work Car including:
 - a) Soil Tiller
 - b) Levelling Blade
 - c) Compactor
 - d) Water Misting Tube

4.1.1 Soil Bin and Associated Equipment

The soil bin facility is 40 ft long with a soil section 60 in. wide and 30 in. deep. The rail-mounted test carriage provides mounting for wheels under loads of up to 2,000 lb at speeds of 1 to 4 fps and up to 1,000 lb at 1 to 10 fps. A variable speed ac drive system is used to propel, brake, and control the carriage. The carriage, with its associated dynamometer and wheel testing, includes means for measuring drawbar-pull, wheel torque, sinkage, speed, and slip.

The work car, mounted on the rail system, includes soil preparation equipment.

4.2 Soil Preparation Techniques

Different techniques for preparing the soil, utilizing the work car, shall be tried until two or more methods are perfected that produce two separate soil conditions whose land locomotion soil values fall within the limits specified in para. 3.2. These procedures shall be documented and two procedures shall be selected and used to produce uniform soil conditions for the wheel tests.

4.3 Test Procedures

Soft soil mobility tests shall be conducted in accordance with the procedures described in paragraphs 4.3.1, 4.3.2, 4.3.3, and 4.3.4.

4.3.1 Drawbar-Pull and Thrust vs Slip Tests

Drawbar-pull and thrust vs slip tests shall be conducted on the test article described in para. 3.1 in two soil conditions falling within the limits specified in para. 3.2. The test sequence shall be as follows.

4.3.1.1 Soil Preparation

Prior to the start of each test, the soil shall be prepared following the procedures developed while performing para. 4.2.

4.3.1.2 Measurement of Soil Parameters

At the start, completion, and when necessary during each day's testing, two penetration and one shear test shall be conducted at three locations in the soil bin using the Bevameter soil test device. Values of the soil parameters k_c , k_θ , n , c , and θ shall be determined from these test data.

4.3.1.3 Data Runs

Drawbar-pull and thrust vs slip tests shall be conducted at a normal wheel load of 57 lb and at wheel loads of 45 lb and 75 lb. Each test run shall be repeated at least once or as many times as required to obtain reasonable agreement between test data from consecutive runs. The wheel and test carriage shall start at a predetermined synchronous speed (0 slip condition) and the speed of the test carriage shall be decreased in a continuous manner to 0 speed with the wheel speed held constant (100% slip condition). The rate of decrease in carriage speed shall be adjusted in such a manner as to use the entire usable bin length in conducting the test. Drawbar-pull, wheel torque (calibrated as thrust), wheel sinkage, revolutions, carriage speed, and normal load shall be recorded on a strip chart recorder.

One test run shall be considered to include two passes, at a given load, through the soil bin, at one soil condition, where the first pass is in freshly prepared soil and the second pass is in the rut of the first pass.

4.3.2 Motion Resistance Tests

Motion resistance tests shall be conducted on the test article described in para. 3.1 in two soil conditions falling within the limits specified in para. 3.2. The test sequence shall be as follows:

4.3.2.1 Soil Preparation

As in para. 4.3.1.1.

4.3.2.2 Measurement of Soil Parameters

As in para. 4.3.1.2.

4.3.2.3 Data Runs

Motion resistance tests shall be conducted at a normal wheel load of 57 lb and at wheel loads of 45 lb and 75 lb. Each test run shall be repeated at least once or as many times as required to obtain reasonable agreement between test data from consecutive runs. To perform the motion resistance test, the carriage shall be run at constant speed for the full length of the soil bin with the wheel in a free-wheeling mode (drive chain detached). Motion resistance, wheel revolutions, carriage travel, normal load, and wheel sinkage shall be recorded. One test run shall consist of two passes at a given load through the bin at one soil condition where the first pass is in freshly prepared soil and the second pass is in the rut of the first pass.

4.3.3 Effective Radius Tests

Effective radius tests shall be conducted on the test article described in para. 3.1 in two soil conditions falling within the limits specified in para. 3.2. The test sequence shall be as follows:

4.3.3.1 Soil Preparation

As in para. 4.3.1.1.

4.3.3.2 Measurement of Soil Parameters

As in para. 4.3.1.2.

4.3.3.3 Data Runs

Effective radius tests shall be conducted at a normal wheel load of 57 lb, and at wheel loads of 45 lb and 75 lb. Each test run shall be repeated at least once or as many times as required to obtain reasonable agreement between test data from consecutive runs. The wheel and test carriage shall start at a predetermined speed to create the following slip conditions: 0%, 5%, 10%, 20%, and 30%. These speeds shall be maintained for the full test. The test shall be run for the full length of the soil bin. The number of wheel revolutions and the exact length of wheel travel shall be recorded in the log book. One test shall be considered to include one pass at each slip through the soil bin at one soil condition.

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4.3.4 Drawbar-Pull and Thrust vs Slip Test in Cohesive Soil

Drawbar-pull and thrust vs slip tests shall be conducted on the test article described in para. 3.1 in a soil condition described in para. 3.2, but where c is higher than 0. The test sequence shall be as follows:

4.3.4.1 Soil Preparation

Prior to the start of each test, the soil shall be prepared following the procedure developed while performing para. 4.2, except the soil shall be sprayed with a fine spray until the value of c approaches but does not exceed $0.05 \text{ lb} \cdot \text{in}^2$.

4.3.4.2 Measurement of Soil Parameters

As in para. 4.3.1.2.

4.3.4.3 Data Runs

Drawbar-pull and thrust vs slip tests shall be conducted at a normal wheel load of 57 lb. Each test run shall be repeated at least once or as many times as required to obtain reasonable agreement between test data from consecutive runs. The wheel and test carriage shall start at a predetermined synchronous speed (0 slip condition) and the speed of the test carriage shall be decreased in a continuous manner to 0 speed with the wheel speed held constant (100% slip condition). The rate of decrease in carriage speed shall be adjusted in such a manner as to use the entire usable bin length in conducting the test. Drawbar-pull, wheel torque (calibrated as thrust), wheel sinkage, revolutions, carriage speed, and normal load shall be recorded on a strip chart recorder.

One test run shall be considered to include two passes through the soil bin where the first pass is in freshly prepared soil and the second pass is in the rut of the first pass.

5. TEST CONDITIONS

5.1 All tests shall be conducted under room ambient conditions and in the soils specified in para. 3.2.

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6. REQUIREMENTS

6.1 General

Since the purpose of these tests is the evaluation of soft soil mobility performance of the DLRV wire frame wheel, there are no specific performance requirements to be met.

6.2 Performance

Testing in accordance with this specification shall be the measure of the soft soil mobility performance of the DLRV wire frame wheels.

6.3 Documentation

All data shall be recorded on approved log sheets or collected on instrumentation read-out charts. Each sheet of data shall be signed by the person responsible for taking the data and the responsible engineer supervising the test. In addition, a log book with approved log sheets shall be maintained daily, noting the test activity for the day, problems, test conditions, and other pertinent data that might not otherwise be recorded. In addition, unique test conditions noted during actual testing shall, when practical, be recorded photographically.

SPECIFICATION

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NO.	REV
ES10115	
SHEET 1 OF 4	
CODE IDENT NO. 13160	

WHEEL ASSEMBLY DUAL-MODE LUNAR ROVING VEHICLE (DLRV) ENGINEERING SPECIFICATION FOR

1. SCOPE. This specification establishes the design, performance, and acceptance requirements for the Wheel Assembly of the Dual-Mode Lunar Roving Vehicle (DLRV).
2. APPLICABLE DOCUMENTS. The following documents form a part of this specification to the extent specified herein. Unless a specific issue is noted in this listing, the issue in effect on date of contract shall apply.

STANDARDS

Military

MIL-STD-129	Marking for Shipment and Storage
MIL-STD-130	Identification Marking of U.S. Military Property

DRAWINGS

AC-DRL

RSK 20141	Wheel Assembly - Open
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PUBLICATIONS

AC-DRL

AC-STD-1	Workmanship
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3. REQUIREMENTS

3.1 Functional Characteristics

3.1.1 Wheel Deflection: The wheel assembly (mesh tire) shall deflect $1\frac{3}{4} \pm 1/4$ inches with an applied vertical load of 57 lbs(f). The minimum deflected radius is 14.25 inches. The nominal total deflection shall be in accordance with Figure C-1.

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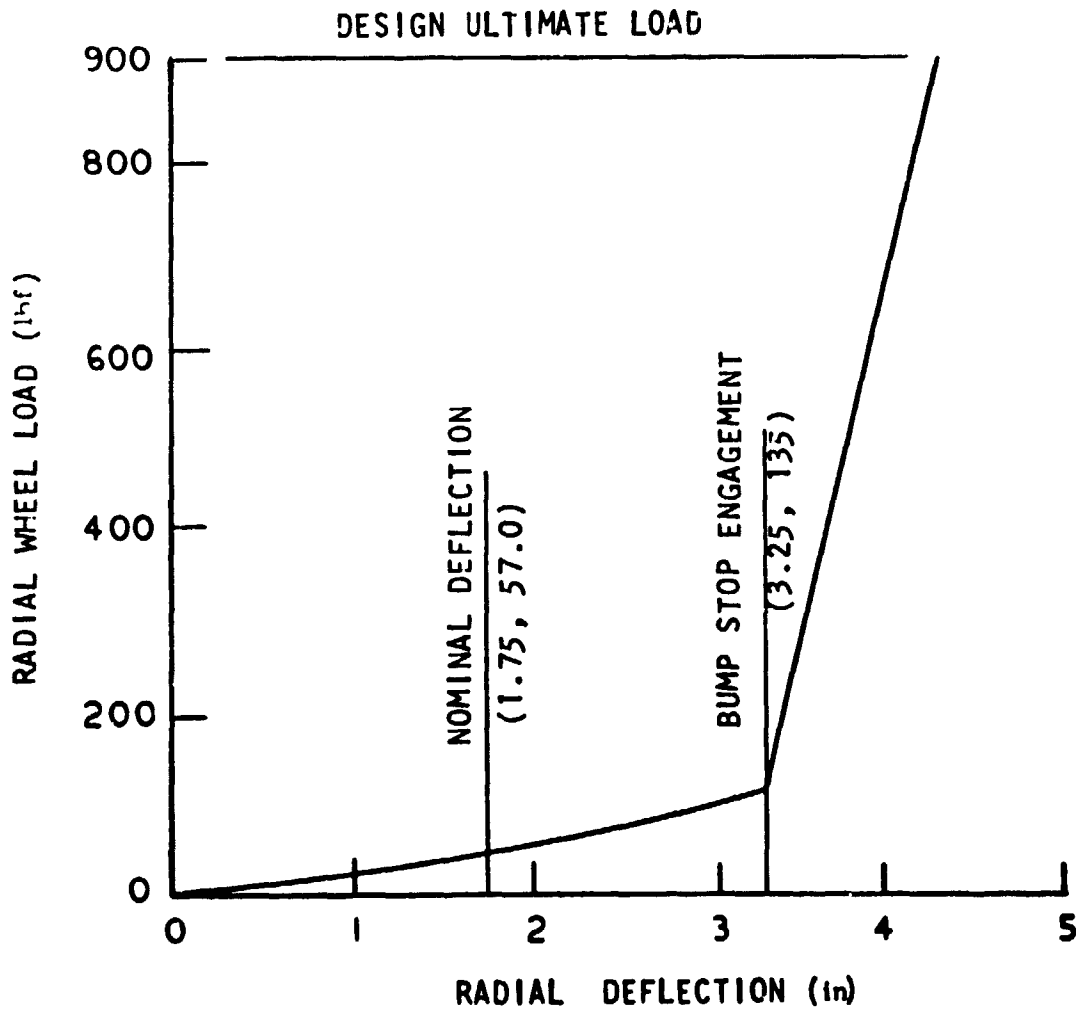


Figure C-1

DLRV WHEEL - LOAD/DEFLECTION CHARACTERISTICS

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3.2 Design Characteristics

3.2.1 Baseline: The wheel assembly shall be to the baseline shown in RSK 20141.

3.2.2 Weight: The total weight of each wheel assembly shall not exceed 12.4 lbm, including tire, hub, and attachment hardware.

3.2.3 Freewheeling: Each wheel assembly must be capable of being disconnected from the motive power source, and put in a freewheeling condition.

3.2.4 Workmanship: Workmanship shall be in accordance with AC STD I.

3.2.5 Identification and Marking: The assembly shall be identified by name plates or markings as appropriate and affixed in accordance with MIL-STD-129 and MIL-STD-130. All hardware identification data inscribed on the name plates and markings shall be taken from and agree with production drawings and/or their engineering release records.

4. QUALITY ASSURANCE PROVISIONS

4.1 General: The supplier shall be responsible for the performance of all inspection requirements as specified herein.

4.1.1 Inspection Level: The wheel assembly shall be tested and inspected at the assembly level.

4.2 Acceptance Tests: The wheel assembly shall be tested at ambient temperatures and pressures attached to either a holding fixture simulating the traction drive interface or an actual traction drive assembly.

4.2.1 Wheel Deflection Measurement: The wheel assembly shall be mounted and locked in a fixture as specified in paragraph 4.2 and a vertical force of 57 lbs shall be applied to the tire mesh. The deflection shall be as specified in paragraph 3.1.1. The wheel shall be rotated 90° and the test shall be repeated 3 times until 4 positions on the wheel at right angles to each other have been tested and measured.

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4.2.2 Dimensional Inspection: The overall wheel assembly dimensions shall be measured and verified with the requirements of paragraph 3.2.1.

4.2.3 Wheel Assembly Weight: The complete wheel assembly shall be weighed and verified with the requirements of paragraph 3.2.2.

4.2.4 Freewheeling Test: The unloaded wheel assembly, when unlocked in the freewheeling condition per paragraph 3.2.3 shall require a maximum torque of 15 lb-in to start rotating. The test fixture shall represent minimum clearance conditions.

4.2.5 Workmanship: Workmanship shall be inspected to verify that the requirements of paragraph 3.2.4 have been met.

4.2.6 Identification Inspection: The wheel assembly shall be inspected to verify that all identification and markings have been applied in accordance with paragraph 3.2.5.

5. PREPARATION FOR DELIVERY

5.1 Cleaning and Preservation: All deliverable assemblies shall be cleaned and preserved in accordance with AC-DRL standard practice.

5.2 Packaging: All deliverable assemblies shall be packaged for safe transportation by common carrier.

6. NOTES

None